Enhancement of imagery in poor visibility conditions

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ABSTRACT

Current still image and video systems are typically of limited use in poor visibility conditions such as in rain, fog, smoke, and haze. These conditions severely limit the range and effectiveness of imaging systems because of the severe reduction in contrast. The NASA Langley Research Center's Visual Information Processing Group has developed an image enhancement technology based on the concept of a visual servo that has direct applications to the problem of poor visibility conditions. This technology has been used in cases of severe image turbidity in air as well as underwater with dramatic results. Use of this technology could result in greatly improved performance of perimeter surveillance systems, military, security, and law enforcement operations, port security, both on land and below water, and air and sea rescue services, resulting in improved public safety.

Keywords: Retinex, visual servo, image enhancement, poor visibility

1. INTRODUCTION

The Visual Information Processing Group at NASA's Langley Research Center has been supporting the Agency's effort to improve pilot visibility in adverse viewing conditions such as night time, fog, haze, and heavy rain. The primary means of acquiring data has been a sensor pod mounted under the belly of a Boeing 757 containing three different types of cameras: a long wave infrared (LWIR), a short wave infrared (SWIR), and an ordinary color video camera. Although the LWIR and SWIR cameras have been the primary systems used for the collection of poor weather data, the visible camera has also been used to collect data, especially during times of low contrast, daylight visibility. Our focus in this paper will be primarily in using that video and other still imagery to provide examples of enhancements in poor weather conditions.

It has long been a problem to match the digital representation of a captured image with the representation in the eye/mind of the human observer[1]. Even under the best recording conditions and with the best recording equipment, it is virtually impossible to exactly match the observed scene with the recorded image. This is because both the recording and the imaging systems introduce artifacts into the captured image. These artifacts include blurring due to the camera lens and the recording/display system characteristics, the limited dynamic range that the camera can capture, and the signal-to-noise ratio due to the thermal characteristics of the device electronics[2-4]. Thus, in order to match the recorded image to the observed image, the acquired image needs to undergo some processing—e.g., enhancement, restoration, deblurring—in order to adequately represent the directly-observed scene. However, the selection of what processing to apply tends to remain in the hands of a trained operator who selects the appropriate tool based upon his or her experience. Our Group has developed innovative tools that automatically improve upon pilot vision in weather which greatly reduce scene contrast and sharpness. These tools classify the overall brightness, contrast, and sharpness of an image based upon its regional statistics. A suite of processing algorithms can then be applied to the image based upon the classification results. This is discussed in more detail in Section 2. It was during the development of these tools that the value of the application of some of these technologies to homeland security was realized.

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2. PROCESSING TOOLS

The Group's primary enhancement tool for use in aviation imagery has been the Multiscale Retinex (MSR)[5,6]. When Edwin Land[7] first conceived a model for the human perception of lightness and color, he called it the Retinex, a word coined from the combination of retina and cerebral cortex. This model was extended by Jobson et al.[5,6] as a general purpose image enhancement algorithm that provides simultaneous dynamic range compression and color constancy. Providing dynamic range compression refers to the capability of the process to encompass wide dynamic ranges — scenes that contain both bright and dark regions — without saturating the high intensity values or clipping the low intensity values. Providing color constancy refers to the ability of the algorithm to produce an output color that is independent of the color of the illuminant: a grey object appears to be grey whether it is viewed under sunlit conditions or under neon lights. Both of these properties are useful in providing better visibility in the presence of illumination changes and shadows. Jobson et al.'s Retinex is an attempt to mimic the dynamic range compression and color constancy capabilities of the human visual system. Unlike Land's Retinex, it was *not* developed as a model to explain the functionality of the human visual system. It was developed as a tool for accurate reproduction of imagery, acquired by either analog or digital means, where the scene lighting varies and/or atmospheric conditions hinder good imagery. However, this version of the Retinex could not provide good tonal rendition so the resulting images often appeared to have a grayish overtone[6]. A multi-scale version of the Retinex[6], the Multiscale Retinex, was developed to alleviate these shortcomings of the original algorithm. In addition to its general image enhancement capabilities, the MSR is capable of providing better-than-observed[8] imagery, especially where scene content is greatly obscured, as in the case of rain, fog, or severe haze. Although the MSR has primarily been applied to conventional multi-spectral and infrared image sources, it is just as effective on non-conventional, computational imagery such as grayscale image representations of traditional medical and airport security imagery[9.10].

More recently, the MSR has been used primarily in support of NASA's Aviation Safety and Security Program. The objective in this work has been to develop the capability for helping pilots see in inclement weather by enhancing infrared as well as three-color, visible imagery. This new MSR technology has far-reaching applications beyond aviation safety, and includes areas such as forensic investigations, medical radiography, and consumer imaging. This technology has been available for consumer use in a general purpose software package, from TruView Imaging Company, called PhotoFlair® (www.truview.com). It was through various testing of this technology on a wide variety of natural scenes that its utility in the enhancement of security[6] and surveillance imagery was realized.

After testing several thousand images, the Group searched for a way to classify images and make some decisions such as what processing, if any, might be needed. This led to the development of the visual measures (VM) and corresponding visual servo (VS). The VS classifies an image as good or poor based on its contrast, brightness, and sharpness measures. Corresponding decision criteria are used to either enhance the image using an iterative process or simply pass it through to the output device (Figure 1). Although any contrast enhancement process can be used with the VS, the Group has been working primarily with the MSR because of its proven success in a wide variety of scenes, over a variety of input sources. The VS uses a two-pass, contrast, brightness, and sharpness enhancement phase along with a parametric histogram modification which is triggered in the case of hazy scenes.

The VS contains automatic detection of several poor lighting conditions such as fog, haze and dusk. The enhanced imagery under such conditions often provides better-than-observer performance. At a rough estimate, the visibility in the enhanced imagery is between 50-300% better than unenhanced imagery. Figure 2 shows a comparison of the unenhanced imagery and the VS processed result. The VS automatically detected the very low light level scene at dusk and invoked the appropriate processing parameters for the MSR and the processes that followed it. The final result of applying the VS to this scene is very impressive. Whereas the original dimly-lit scene had very little contrast, so that hardly any detail was visible, the processed scene has the appearance of having being captured in much brighter lighting conditions or at a much longer exposure. The image was taken with a high-end digital camera and an achromatic telephoto lens from a distance of about 1.5 miles in moderate haze.

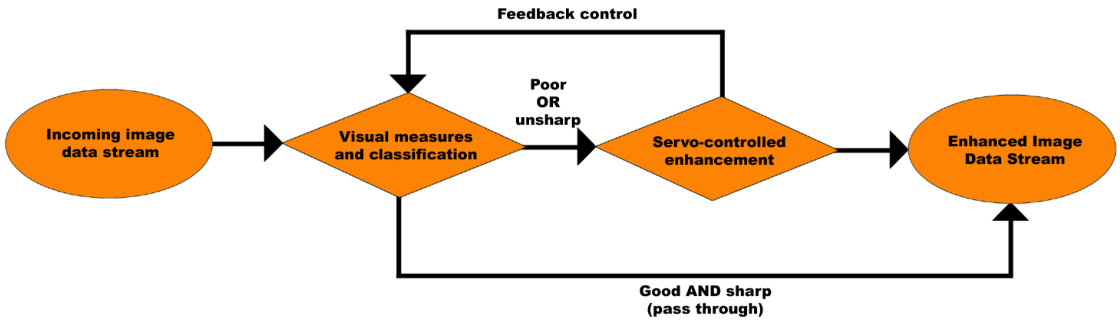

Figure 1. Schematic of VS

The exposure was set to calibrate with what the observer would have seen at that time. The processed results, however, are better than observer in terms of visibility and clarity. This is, in some sense, a subjective test since the observer is relying on what he recalled of the original visibility conditions to make the comparison. However, we have performed this test on hundreds of acquired images and have derived the same conclusion consistently. Our experimental conclusion is that the visual servo does achieve our goal which was to significantly out-perform the human observer in dim light and turbid imaging conditions.

Figure 2. Original image (left) compared with the VS enhanced image (right)

To illustrate the effectiveness of the VS over a wide variety of natural scenes, several examples are illustrated below. All were taken by GAW with a Nikon D1 digital camera with the exception of the underwater scene in Figure 7 which was from an Internet website. Figure 3 shows an image that was acquired during a controlled burn at the NASA Langley Research Center. In this case the poor visibility was not caused by poor lighting or poor weather, but by a man-made event: fire. This example has been shown to illustrate that the VS can compensate for all different types of poor lighting conditions without regard to their origin. Figures 4-7 show several other conditions where imagery has been degraded by poor lighting and weather conditions. Figure 4 shows a large structure under severe fog. The VS brings out the structure with enough detail that a pilot approaching can recognize its magnitude and take evasive action if necessary. Interestingly, because LWIR relies on temperature differential to produce contrast between features, it was unable to provide the necessary differentiation to bring out the metallic structure under these weather conditions. The fog had been on the ground for a considerable length of time and had essentially equalized all temperature gradients. Figures 5 and 6 show images that were taken by the driver of an automobile during heavy rain and snow storms, respectively. In each case, the VS processed image allows the driver considerably more visibility than was available either by direct observation or in the unprocessed image.

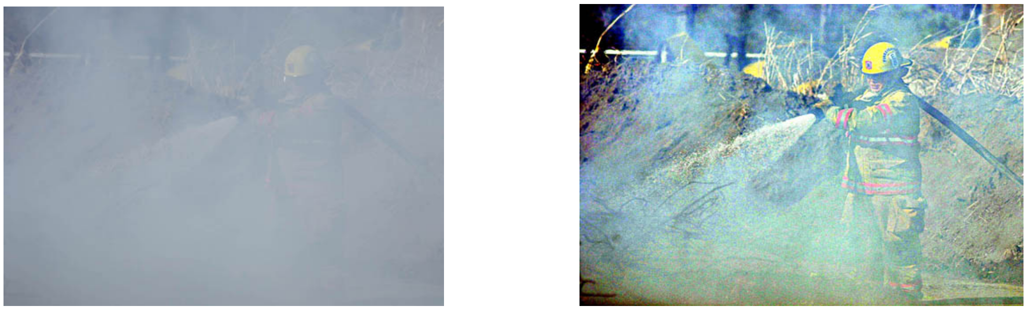

Figure 3. Original image and VS result of scene obscured by heavy smoke. Note abundance of color in processed image.

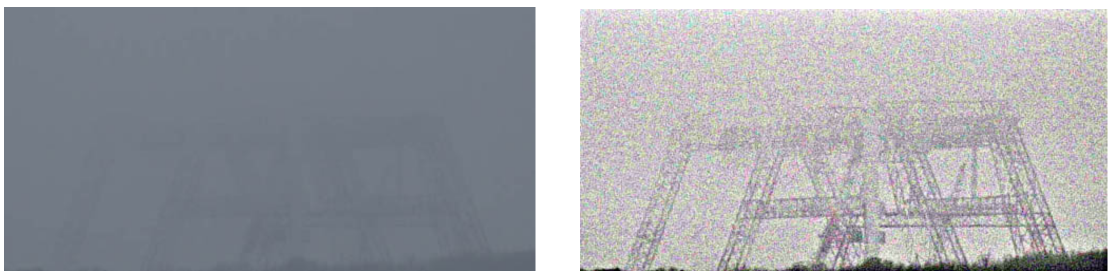

Figure 4. Original image and VS result of image obscured by severe fog at a distance of about 1.5 miles. Note fine detail in structure.

Figure 5. Original image and VS result of image obscured by heavy rain. Note visibility of illuminated tail lights on vehicles ahead.

Figure 6. Original image and VS of image obscured by snow. Note dramatic increase in sharpness and color.

Figure 7 is somewhat of a special case since it does not directly apply to poor weather conditions. However, lighting conditions underwater are typically poor even in shallow water. This figure shows a diver with SCUBA gear. Whereas no distinctive colors are evident in the original image, many different colors are visible in the VS enhanced image. This can be very useful for application such as port security where VS enhancements can be used to improve the visibility of features on underwater objects, making identification much easier.

Figure 7. Original image and VS of scene obscured by water turbidity.

3. COMPARISONS

In use, the VS with the MSR performs extremely well over a wide variety of scenes. Comparisons with other automatic image processing methods have been made, all of which show a very high rate of success for the MSR/VS method[10-12]. Comparisons have been made with Adobe Photoshop® histogram equalization and auto levels, Intrigue Technologies Shadow Illuminator®, Applied Science Fiction Digital SHO®, Extensis Intellihance®, Microsoft Picture It! ® Polaroid Before and After®, and Computerinsel GmbH Photo Line®. Although all of these products perform well on certain scenes, the MSR, especially with the VS, demonstrates superiority over all of these other methods in a far greater number of cases, especially those associated with poor visibility scenes.

4. APPLICATIONS TO HOMELAND SECURITY AND SAFETY

Since the VS works especially well with scenes of very low contrast, it is natural to assume that it will work well in applications where visibility is very poor. Even in clear weather, dimly-lit scenes offer very low contrast. Additionally, scenes that have both very bright and dark regions such as those that have deep shadows also cause problems for most video cameras. In most video surveillance cases, the imagery is either recorded on video tape or stored on a DVD or disk. However, because of the cost, either the same video tape is used again and again, thus destroying the quality of the recorded scene, or the data is heavily compressed to allow longer times to be stored on disk, once again affecting the image quality. For this reason it is imperative that enhancements be performed on the data before storage. Ideally, of course, unprocessed data would be available at the highest possible quality level, but practically, this is hardly ever the case! Given good quality image data, not necessarily good visibility image data, the VS can often extract information that is critical for applications such as perimeter surveillance and facial recognition. We are familiar with the work of at least one research group that is using the MSR as a preprocessor to eliminate shadows and effects due to lighting variation for face recognition algorithms.

The Group has made numerous tests in poor weather including heavy rain, fog, smoke, severe haze, snow, and thin cloud cover. Visibility in these conditions can often be increased by much more than 50%.

Although this does not sound like much of an improvement, especially in severe cases, the benefit can be realized in the temporal domain where an improvement of a mile, in the case of a moving aircraft, can relate to several seconds of critical reaction time. It can mean the difference between a crash and avoiding one, seeing or completely missing a downed pilot in the water, or misidentification of an intended target.

Below, several scenes of poor visibility have been captured and their enhancements are shown. All were captured from Internet sources except for those marked with an asterisk. In those cases the author recorded them with a Nikon D1 digital camera and Nikkor® 80-200mm f2.8 lens. In Figure 8, the directly viewed scene was not as obscured as that in the digital representation but it was very hazy and ground detail was lost. The VS processed image clearly shows details that were not visible by the observer at the time the image was captured.

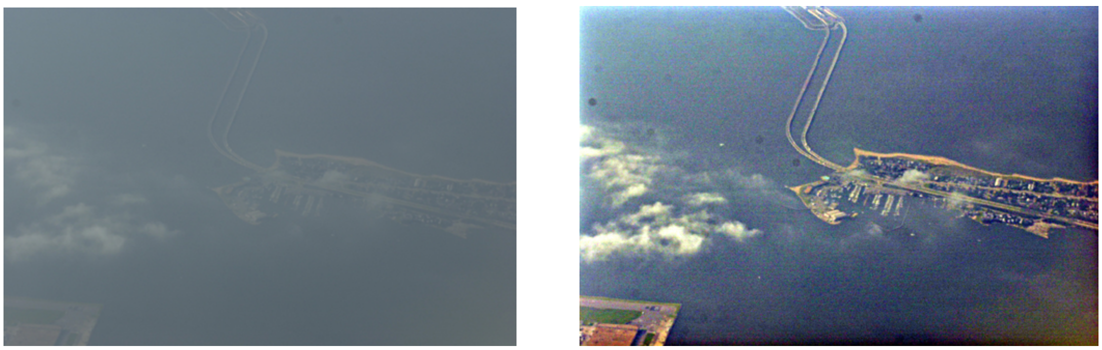

Figure 8. Original* and processed aerial image of bridge obscured by haze, revealing color and detail.

In Figure 9, there was moderate fog being illuminated by the sodium vapor lights, creating glare and reducing visibility, especially in the shadows. This VS enhanced image is one of many where the results were that of a dramatic improvement over the directly-observed scene. Details can be seen in shadowed areas which were not visible at the time of the image capture. There was a dramatic increase in the overall visibility as well as a noticeable but not perfect correction of color under the monochromatic illumination.

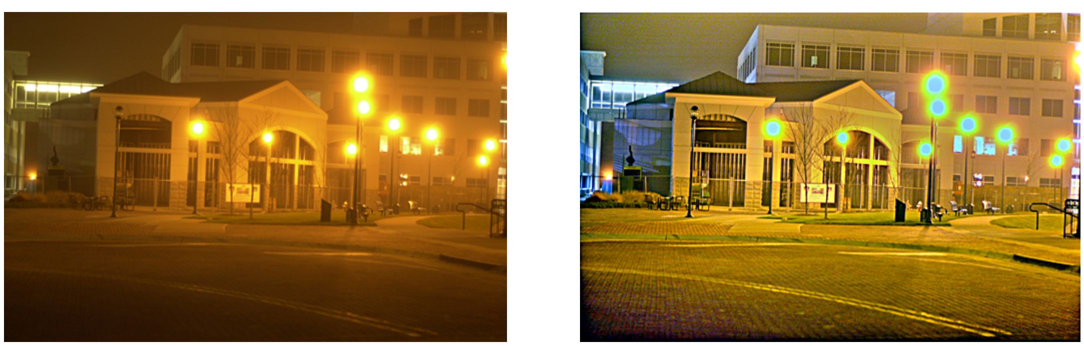

Figure 9. Original* and processed image of public area under fog at night, bringing out detail in the shadows, extending visibility, and providing some color correction.

Figure 10. Original and processed image of rescue training scene obscured by haze and water spray showing increase in contrast and sharpness.

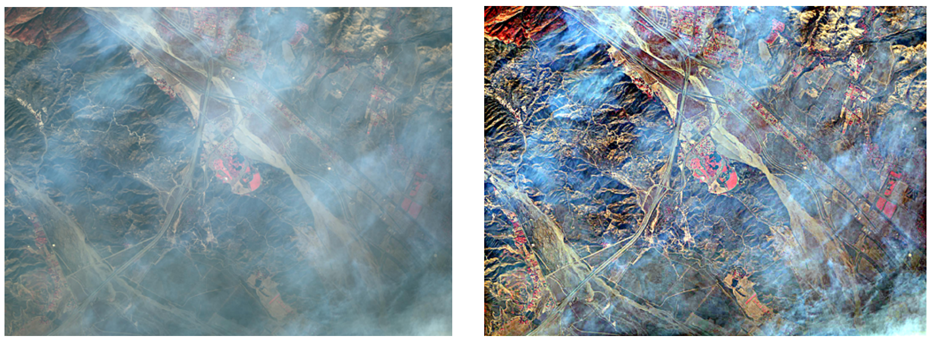

Figure 11. Original and processed image of scene obscured by smoke, revealing ground features lost to low contrast.

Figures 10 and 11 were captured from web pages and as such had relatively high JPEG compression. Even so, the enhancements were striking. The helicopter in Figure 10 shows very little detail in the original image but after enhancement, details in the rotor blades, the body, and the surface of the water are obvious. Even the color is much closer to what one would expect. Figure 11 was taken from the air over a wildfire. Although some ground detail is evident in the original, the enhanced image shows much more detail in the ground below. Even the bright areas are enhanced without saturation and some vehicles can be seen on the highway. In Figure 12, the face of the driver in the truck was clearly visible but due to the narrow dynamic range of the camera system, including the slight JPEG compression, the details were eventually lost in the shadows. The processed image is at least equivalent to the directly-viewed scene. This scene did not suffer from low contrast but rather the opposite   very high dynamic range resulting in the need for effective dynamic range compression.

Figure 12. Original* and processed image of scene with bright illumination and dark shadows, revealing details in face while preserving detail in bright areas.

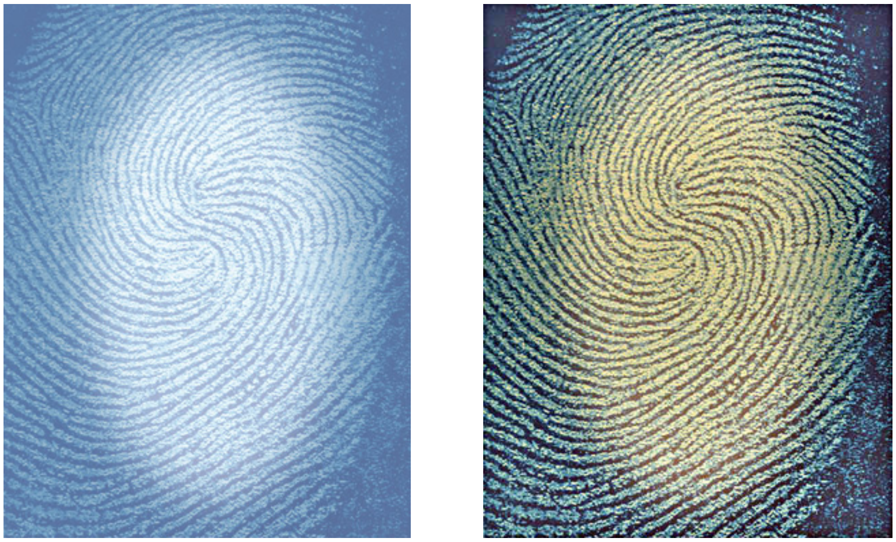

Figure 13. Original and processed image of latent fingerprint, demonstrating reduced lighting variations and more detail.

Figure 14. Original and processed image of satellite view of Baghdad, Iraq, revealing ground details and increasing sharpness under haze and cloud shadows.

The image of the fingerprints in Figure 13 is pretty good already but enhancing with the VS shows a dramatic increase in local as well as global contrast. This global contrast enhancement actually causes an overall darkening of the scene but it stays sufficiently bright and remains a much better image over the original. The lines in the print seem much more connected with those outside of the illuminated area.

Figure 14 is very typical of the vast majority of satellite data that the Group has enhanced. These scenes usually contain areas of dark shadows under the clouds where almost all color is lost. In this enhanced view, color is restored, details in the water itself are evident, and the effect of the cloud shadow is almost eliminated.

The underwater scene in Figure 15 is just one of many of the most dramatic cases demonstrating the performance of the VS. Note the increase in overall color saturation due to the increase in local contrast and sharpness. Visibility of fine detail has been increased to the entire field of view.

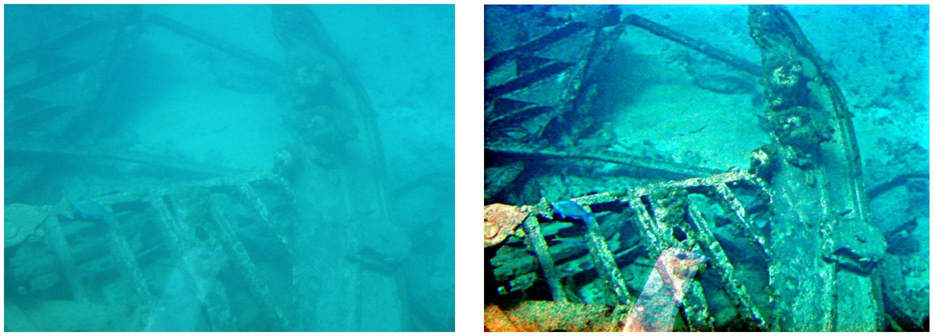

Figure 15. Original and processed image of underwater scene, showing dramatic enhancement of features, saturation of color, increase in visibility, and overall sharpness.

In Figure 16, the colors in the glory on the cloud were only visible to the author when viewed through polarized sunglasses. They were not visible without them nor were they visible in the unprocessed original image. The detail on the ground was just barely visible but nowhere as obvious as in the VS processed image. Much of the detail in the sunlit cloud was not visible unless viewed through sunglasses however the processed image brings out the detail that appears lost in the original image. This example demonstrates again, the utility of the MSR in wide dynamic range scenes.

Figure 16. Original* and processed image of shadowed ground through heavy haze and under bright clouds, revealing much detail on ground. Note colors of glory on cloud.

Figure 17 is indicative of the many X-ray and other medical images that the Group has tested. The nature of the wide dynamic range but low contrast of X-rays makes them a great candidate for processing, especially when viewing them on relatively narrow, 8-bit displays and other output devices. The details in sufficiently bright areas can be preserved while bringing out great detail in the dark areas.

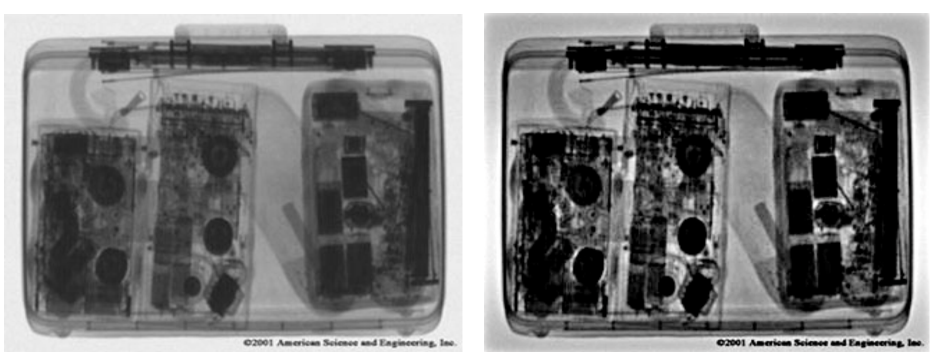

Figure 17. Original and processed image of baggage from airport X-ray. Enhancement provides a much sharper image and reveals small details with a dramatic increase in contrast.

Visual Servo enhancements of video have shown equally good results. Although the VS/MSR process does increase the effect of noise in images by treating the noise as data, the randomness of it diminishes its effect when viewed at video rates. FLIR and visible data from the Langley Aviation Safety Program is almost entirely in the form of video.

Originally used in software form, the MSR has been implemented in a digital signal processor[13] for upcoming real-time Aviation Safety studies. A Texas Instruments TMS320C6711 floating point DSP is being tested for use in capturing NTSC video of pilot views on Langley's Boeing 757. Video frame rates have been realized in single scale/single band mode although a newer processor, the Spectrum Digital EM642 has performed at 90 frames per second in this mode. Other video studies have been made by post-processing from a number of sources.

Stills from many video sources have been processed in support of several local and national criminal investigations. Most notable of these was the South Charleston, West Virginia Target Department Store child molestation case in 2003. After an MSR-processed image of his face was shown on national television, the suspect was identified by a relative, arrested, and convicted in court.

CONCLUSIONS

The effectiveness of Langley's Multi-scale Retinex combined with the Visual Servo has proven is superiority over other automatic methods of image enhancement. Its dramatic performance with a strong increase in local contrast and overall sharpness, especially in scenes of poor visibility, make it a prime candidate for homeland security and safety duties. Its usefulness in aviation safety has already proven itself and work is under way to develop an inexpensive real-time implementation for fixed as well as portable applications. These applications include systems to be used in clear and especially poor visibility conditions such as aircraft and automotive heads down or heads up displays, search and rescue operations, underwater operations, aerial and satellite reconnaissance, firefighting, and military use, or anywhere public security and safety are a concern.

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